DOCUMENT RESUME

ED 317 422 SE 051 340

| | |
|---|---|
| TITLE | Federal Support for Undergraduate Laboratory Work in Physics. A Statement by the American Association of Physics Teachers. |
| INSTITUTION | American Association of Physics Teachers, College Park, MD. |
| PUB DATE | 89 |
| NOTE | 13p. |
| AVAILABLE FROM | American Association of Physics Teachers, 5112 Berwyn Road, College Park, MD 20740 (free while supply lasts). |
| PUB TYPE | Reports - Descriptive (141) -- Viewpoints (120) |
| EDRS PRICE | MF01/PC01 Plus Postage. |
| DESCRIPTORS | *College Science; *Federal Aid; Financial Support; Higher Education; *Laboratories; *Laboratory Equipment; *Physics; Science Equipment; *Science Laboratories; Undergraduate Study |

ABSTRACT

The teaching laboratory in physics departments in colleges and universities is a source of great potential strength in undergraduate education. Recent surveys and conferences, have identified inadequate teaching equipment and laboratory development. This report reviews these problems and offers suggestions for an enhanced federal effort to solve them. The role of experimental work in undergraduate physics and the need for improvement of instrumentation and course content are described. The objectives and history of the National Science Foundation's improvement program are outlined. The negative consequences of exclusion of doctoral institutions from the program support are discussed. Recommendations are made related to: (1) locus of responsibility; (2) funding; (3) terms of the competition; (4) laboratory development; (5) budget items; (6) improvement of the present situation; (7) regular evaluation; and (8) responsibilities of physics departments and their institutions. (YP)

**********
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
**********

ED317422

# Federal Support for Undergraduate Laboratory Work in Physics

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

Donna J. Willis

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

This document has been reproduced as received from the person or organization originating it.

Minor changes have been made to improve reproduction quality.

Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

**A Statement by the American Association of Physics Teachers**

**February 1, 1989**

SE051340

# Federal Support for Undergraduate Laboratory Work in Physics

---

**A Statement by the American Association of Physics Teachers**

**February 1, 1989**

© 1989, American Association of Physics Teachers

**Published by:**
**American Association of Physics Teachers**
**5112 Berwyn Road, College Park, MD 20740, (301)345-4200**

Additional copies are available without charge at the above address while the supply lasts. Inquiries and comments should be directed to Jack M. Wilson, Executive Officer, American Association of Physics Teachers.

## Executive Summary

The teaching laboratory in physics departments in the Nation's colleges and universities is a source of great potential strength in undergraduate education. In surveys and conferences, physics department chairpersons have repeatedly identified inadequate teaching equipment and laboratory development as their most troubling problem in undergraduate education. In recent years, specifically, the undergraduate laboratory has deteriorated in most physics departments as equipment becomes inoperable or obsolete and institutions lack the means to replace it or upgrade it. Development of new course content to reinvigorate the teaching laboratory has also lagged. Similar problems exist in other disciplines.

To assist science departments to meet this problem, the National Science Foundation launched the valuable College Science Instrumentation Program in FY 1985 to provide funds on a matching basis for the purchase of instrumentation for undergraduate laboratories in non-doctoral, four-year institutions. Renamed the Instrumentation and Laboratory Improvement Program in FY 1988, the program continued to provide much-needed assistance in science, engineering, and mathematics to bachelors and masters programs and two-year institutions. Grants were not made, however, to doctorate-awarding institutions until FY 1989 when it was announced that some awards would be made to smaller doctoral institutions.

In the present report, the American Association of Physics Teachers (AAPT) reviews this pressing educational problem and offers suggestions for an enhanced Federal effort to solve it. One issue of great importance is the inability of NSF to provide support hitherto to doctoral institutions. Physics departments in such institutions are responsible for roughly half of all undergraduate education in physics and report that they are unable to maintain their undergraduate physics laboratories adequately within presently available financial resources. Among the AAPT recommendations are the following:

- The Directorate for Science and Engineering Education of NSF should be assigned the sole responsibility within NSF for administering an expanded Instrumentation and Laboratory Improvement Program (ILIP) to which bachelor's-, master's-, and doctor's-degree institutions and two-year colleges would be eligible to apply on equal terms.
- Add-on funds should be provided in the ILIP budget, bringing the total (all fields) to $25,000,000 in FY 1990 and $27,000,000 in FY 1991.
- All eligible institutions – two-year and four-year colleges and master's and doctor's-degree awarding institutions – should compete for ILIP awards from a common pool of funds under uniform standards for judging proposals in all fields of NSF support.

## I. Introduction

*The role of experimental work in undergraduate physics.*

The teaching of physics in the Nation's colleges and universities historically has depended heavily on laboratory work – "hands-on experience" – by undergraduates from the introductory course to more advanced work by undergraduate majors. To be sure, laboratory work must proceed apace with learning about the concepts of physics and about models of the physical world – what the layman would call the "theory" side of physics teaching. Some teachers have placed more emphasis on the one than the other. Many have questioned how laboratory work could best be organized to make an effective contribution to learning. None, it is fair to say, would deny the essentiality of some form of work with real physical systems.[1]

Recent reports have identified the teaching laboratory as a source of great potential strength, but also as a matter of present concern. The 1986 "Neal Report" of the National Science Board provides an example:[2]

> Science and engineering are strongly observational and experimental in nature. The laboratory experience is a central and essential element in the undergraduate training of students in these areas. Through the experiences of collecting data and interpreting them, students can come to understand the underlying principles of the disciplines and how science and engineering are really done. Thus, the quality and effectiveness of the curriculum overall is strongly dependent on the strength and currency of the laboratory component.
>
> There are strong indications that the quality of undergraduate science and engineering laboratory instruction has deteriorated significantly in recent years. Reports and testimony to the Committee indicated that much instrumentation in undergraduate laboratories throughout the U.S. is either worn out or obsolete in the face of rapid advances in science and technology.

Another 1986 report, prepared for the Congress by the Office of Technology Assessment and entitled *Scientific Equipment for Undergraduates: Is It Adequate?*, has this to say:[3]

> A general concern is that new science and engineering graduates have spent much less time in the laboratory than was common a decade ago. Some industry employers stated that their new employees appeared to have a more theoretical and less hands-on education than the employers had expected. Thus, they require more on-the-job training.

**II. The Need for Improvement of Instrumentation and Course Content**

The present statement by the American Association of Physics Teachers (AAPT) will address itself to the role of the Federal government in helping to solve this problem. It will emphasize two elements of the problem:

- instrumentation needs, and
- the need for improvement of course content in the laboratory.

While a serious problem is to be found in physics departments of every type, attention needs to be paid especially to doctoral departments (those in institutions that award doctorates in physics), because until FY 1989, none of these departments have been able to obtain support from any major undergraduate-oriented Federal instrumentation program.

*A. Instrumentation needs.*

To a greater degree than in other basic sciences, physics requires sizable amounts of capital equipment in its teaching laboratories, but comparatively small amounts of expendable supplies. Over the years, physics departments have built up inventories of teaching equipment, some of it in multiple set-ups to accommodate introductory laboratory classes, some of it one-of-a-kind items to be used by advanced undergraduates. The equipment is used year after year, experiencing heavy wear and tear. It is repaired by the department's technicians, until it is beyond repair or has become hopelessly obsolete.

In recent years, the equipment inventory has deteriorated. At the Physics Department Chair Conference on the Education of Physicists (September 30–October 1, 1983), with an attendance of 163 chairpersons, the group discussing equipment needs reported:[4]

> It was clear from the discussion that most if not all colleges and universities in this country are suffering from a shortage of up-to-date laboratory equipment. Most undergraduate laboratories are instrumented with antiquated equipment which is often in need of repair. There was a strong sense of frustration expressed due to the lack of funds available at either a local or national level to begin to rectify this situation.

These conclusions were given wide dissemination afterwards and were the principal point made in testimony before the House Committee on Science and Technology (1985) by the President and Executive Officer of AAPT.

In preparation for the Second Physics Department Chair Conference (Education for Professional Work in Physics) (May 17–18, 1985, attendance 150), the American Physical Society conducted a survey of physics departments.[5] Physics departments of all types placed "the laboratory equipment problem" at the top of those that should be stressed in proposing new initiatives to funding agencies (Table 1).

The following categories of equipment were those of primary concern:

- Replacements for standard equipment that has deteriorated through long and hard use. Examples are electrical measurements instruments, balances, oscilloscopes, spectrometers, and air tracks.
- Equipment with which to carry out innovations in teaching: e.g., microcomputers, computer-interfacing equipment, and lasers.
- Equipment with which to carry out experiments in modern physics: e.g., apparatus for investigating superconductivity, microelectronics, modern optics, atomic physics, and nuclear physics.

**Table 1. Priorities for Recommending Initiatives for Funding Agencies in Undergraduate Physics Education by Institutional Type (3-point scale; 3 = highest priority). SOURCE: Robert Resnick, 1986, loc. cit.**

| | |
|---|---|
| 1. Laboratory Equipment | |
| ALL | 2.0 |
| PhD | 2.1 |
| MS | 2.1 |
| BA | 2.0 |
| 2. Undergraduate Research Programs | |
| ALL | 1.0 |
| PhD | 0.9 |
| MS | 1.0 |
| BA | 1.0 |
| 3. Computer Access | |
| ALL | 0.66 |
| PhD | 0.83 |
| MS | 0.90 |
| BA | 0.53 |
| 4. Curriculum Development | |
| ALL | 0.61 |
| PhD | 0.50 |
| MS | 0.51 |
| BA | 0.67 |
| 5. New Educational Material | |
| ALL | 0.54 |
| PhD | 0.50 |
| MS | 0.36 |
| BA | 0.59 |
| 6. Visiting Scientist | 0.25 |
| 7. Minority Programs | 0.12 |
| 8. Women's Programs | 0.11 |
| 9. Other | 0.11 |

Comments from physics department chairs responding to the survey throw additional light on the equipment situation:

- "[We] badly need new equipment in introductory labs."
- "[There is a] lack of funds to upgrade advanced labs."
- "Inadequacy of capital equipment funds to upgrade and maintain lab equipment has been detrimental."
- "Our lower division labs are OK, but we need to bring computers into them if our students are to graduate with any sort of modern background. Our advanced labs need refurbishing badly in the area of instrumentation. Money is a serious problem."
- "Financial support for both lab equipment and computers for undergraduate courses is extremely low. Efforts are (as always) being made to upgrade this support. There is no question that inadequate resources in this area have hurt us badly and redressing this situation is a very high priority of the department."
- "We use old equipment or cheap new material. It's really a wonder we ever attract a major. They *do* get the whole attention of a Ph.D. professor in every class and lab."

*B. Course content needs.*

Projects to develop new approaches to laboratory teaching have proved to be extremely valuable. An earlier example is the Berkeley Physics Course Laboratory. More recently programs like the Maryland University Project on Physics and Educational Technology (M.U.P.P.E.T.) have offered the possibility of making major changes in the undergraduate laboratory through an innovative use of microcomputers.[6]

Unfortunately, available support for other projects such as these has been insufficient to meet the need. Yet course-content projects to strengthen the physics laboratory are needed fully as much as those to improve textbooks, visual aids, and the curriculum. Laboratory-development grants provide physics departments with the means to reassess the role of the undergraduate laboratory and to develop new experiments based on apparatus developed specifically for that purpose. Ingenuity for developing such equipment is not lacking, as shown by the success of the biennial Apparatus Competitions of the AAPT. Some of the prizewinning apparatus items in the competitions have subsequently been produced commercially. Additional stimulation and means to support such innovation are needed.

**III. The NSF's Instrumentation and Laboratory Improvement Program**

*A. Objectives and history of the program.*

Initiated in FY 1985 as the College Science Instrumentation Program (CSIP) within the Directorate of Science and Engineering Education, this valuable initiative by the National Science Foundation was designed "to strengthen and support models of excellence in science and engineering instruction in the Nation's non-doctoral [four-year] colleges and universities."[7] It provided "matching support for the purchase of laboratory and instructional equipment to implement new or improved undergraduate programs in science and engineering." Awards were made in the fields of science, engineering, and mathematics.

CSIP had these objectives:

- Introduction of modern instruments to improve the experiences of undergraduate students in science and engineering courses, laboratories, and field work;
- Interfacing of computers with scientific instrumentation and other appropriate uses of current technology in science and engineering instruction;
- Development of new ways of using instrumentation to extend instructional capabilities; and
- Establishment of equipment-sharing capability via consortia or centers.

NSF has described CSIP as "highly competitive" and as characterized by the following strategy:

- "To support projects that set standards for instrumentation and its use against which other institutions could measure themselves and which they would strive to achieve."
- "To produce laboratory manuals, scholarly publications, etc. that would extend the benefits beyond local improvements."

The operation of the program was described as follows:

> The program supports well-focused projects which will result in a clear improvement in the quality of undergraduate education. This is done by providing for:
>
> - Acquisition of new, state-of-the-art instructional scientific equipment;
> - Upgrading of existing equipment; and
> - Replacement of non-functional or clearly obsolete equipment.
>
> Because the objective of the program is to improve the quality of instruction, projects are expected to involve activities which go beyond the basic

level of support from the institution necessary to ensure a viable program. Activities supported by CSIP include the improvement of formal laboratory courses associated with undergraduate instruction, the enhancement of undergraduate student research, projects aimed at acquainting nonscience majors with principles and methods of science and engineering, and projects concerned with improving undergraduate science education of prospective teachers. The Foundation is also concerned about the underrepresentation of women, minorities, and handicapped persons in careers in mathematics, science and engineering, and supports projects whose target audiences are students in these groups.

Grants in support of CSIP activities are made for a 2-year period. The minimum allowable CSIP award is $5,000, and the maximum is $50,000; the grantee institution must provide an equal or greater matching contribution.

In FY 1988, the program was renamed the Instrumentation and Laboratory Improvement Program (ILIP). Its basic objectives and style of operation remained the same, but two-year and community colleges were made eligible to apply and some of these received awards. Proposals from doctorate-awarding institutions were also invited, but, for reasons detailed below, it was not possible to make awards to such institutions in FY 1988.

*B. How CSIP/ILIP support has been distributed.*

Total awards in the program have risen from $5.48 million in FY 1985 to $10.9 million in FY 1988. Awards to physics departments (including astronomy) in non-doctoral institutions were $586 thousand in FY 1985 and $718 thousand in FY 1988. Table 2 contains program data for all disciplines in this same time span. Awards have covered a wide range of geography and types of institutions. They also have included projects for undergraduate student research, for nonscience majors, for undergraduate science education of prospective teachers, and for women, minorities, and the handicapped.

Budgeted funds for the program in FY 1989 are $20.5 million: $16 million within the budget of the Science and Engineering Education Directorate (including about $3 million to fund awards resulting from FY 1988 proposals by smaller doctoral institutions) plus $4.5 million within the budgets of the Research Directorates.

A few comments about the physics proposals and awards seem appropriate. First, the "success ratio"—the ratio of awards to proposals—for physics is roughly the same as the overall (all fields) success ratio. In physics, this ranged from a low of 0.19 in FY 85 to a high of 0.33 in FY 87; for the same years, the overall ratios were 0.17 and 0.35. The average of dollars awarded in physics, however, was less than the average award in all fields. In physics, the average award each year from FY 85 to FY 88 ranged from a low of $16,700 in FY 87 to a high of $21,800 in FY 88; the average overall award was $25,400 in FY 87 and $30,100 in FY 88. Inspection of the grants announcements indicate that the most frequent successful requests in physics were for microcomputers, computer interfacing equipment, and modern optics apparatus. Roughly 10% of the physics awards were for equipment in astronomy.

**Table 2. Proposals by Discipline, Total Awards, and Physics Awards, CSIP/ILIP, FY 85—FY 88. SOURCE: National Science Foundation**

| Proposals | 1985 | 1986 | 1987 | 1988 |
|---|---|---|---|---|
| Biological Sciences | 278 | 189 | 200 | 353 |
| Chemistry | 364 | 259 | 227 | 418 |
| Computer Science | 77 | 54 | 67 | 143 |
| Engineering | 134 | 101 | 167 | 628 |
| Interdisciplinary | 136 | 69 | 57 | 101 |
| Mathematics | 21 | 10 | 19 | 100 |
| Physics | 161 | 105 | 105 | 231 |
| Psychology | 88 | 56 | 58 | 60 |
| Other Social Sciences | 34 | 26 | 22 | 55 |
| Total | 1348 | 924 | 970 | 2217 |

| Awards | 1985 | 1986 | 1987 | 1988 |
|---|---|---|---|---|
| No. of Awards | 234 | 211 | 337 | 362 |
| Dollars Awarded | 5.48M | 4.95M | 8.55M | 10.9M |
| No. of Physics | 30 | 22 | 35 | 33 |
| Physics Dollars | 586K | 414K | 584K | 718K |

*C. Value of the program to non-doctoral institutions.*

The data given above show that over $4.6 million (including matching funds) has been provided to some 120 physics departments in bachelor's-degree, master's-degree, and two-year institutions. These departments offer ample evidence of its value to their undergraduate programs. The infusion of new equipment and the provision of opportunities to rethink the purposes of the teaching laboratory and the needs of today's students have helped to revitalize the teaching of physics in those institutions. Physics faculties have become committed and involved in the task of improving the laboratory experience of undergraduates. College administrations have welcomed the assistance of the National Science Foundation and have made special efforts to provide the matching

funds required. Above all, their students – estimated at 150,000 – have benefitted from more valuable and exciting laboratory work. Continuation and even enhancement of such support are clearly needed.

***D. Exclusion of doctoral institutions from program support.***

Unfortunately, the National Science Foundation was not able to make awards to doctorate-granting institutions until FY 1989 when a small beginning was made, leaving CSIP/ILIP not flawed, but incomplete.

The reasons for exclusion of doctoral institutions had to do with the availability of funds to NSF and with the assignment of responsibilities and dollars within the Foundation. ILIP support for doctorate-granting institutions was intended to be budgeted and managed by the NSF research directorates. Although NSF invited proposals from doctoral institutions for FY 88 awards, the final FY 88 budget for the research directorates was considerably less than the amount requested, and no funds were made available within NSF for ILIP awards to doctoral institutions. Any proposals received from such institutions were reviewed but not funded. NSF announced that it planned to carry over all such proposals to FY 1989 and to reconsider them at that time. As indicated above, this plan is currently active. The strong interest among doctoral institutions in ILIP in FY 88 is shown by the proposal data in Table 3.

**Table 3. FY1988 Proposal Data, ILIP. Source: National Science Foundation.**

| Institution Type | Total Proposals | Physics Proposals |
|---|---|---|
| Doctoral | 921 | 95 |
| B.S. and M.S. | 1,119 | 114 |
| Two-year | 177 | 21 |
| Totals | 2,217 | 230 |

**TABLE 4. Enrollments and Bachelor's Degrees in Physics by Institution Type. SOURCE: American Institute of Physics, Pub. No. R-151.25, July 1988.**

**Introductory Physics Course Enrollments***
**1987–88**

| | Number | % |
|---|---|---|
| Bachelor's-granting institutions | 64,480 | 25 |
| Master's-granting institutions | 36,400 | 14 |
| Doctorate-granting institutions | 159,120 | 61 |
| Total | 260,000 | 100 |

**Undergraduate Physics-Major Enrollments**
**1987–88**

| | Juniors | | Seniors | |
|---|---|---|---|---|
| | Number | % | Number | % |
| Bachelor's institutions | 2511 | 39 | 2218 | 37 |
| Master's institutions | 871 | 14 | 750 | 13 |
| Doctoral institutions | 3030 | 47 | 2991 | 50 |
| Total | 6412 | 100 | 5959 | 100 |

**Bachelor's Degrees Awarded in Physics**
**1986–87**

| | Number | % |
|---|---|---|
| Bachelor's institutions | 2120 | 40 |
| Master's institutions | 660 | 13 |
| Doctoral institutions | 2473 | 47 |
| Total | 5253 | 100 |

* Includes engineering majors, physical sciences majors, biology majors, health-related majors (pre-meds, predents), and others (non-science majors – elementary education, law, journalism, etc.)

## IV. The Consequences of the Exclusion of Doctoral Institutions

***A. The role of doctoral physics departments in undergraduate physics education.***

Institutions with doctoral programs in physics are sometimes thought to be minor performers in undergraduate physics education and thought to devote themselves to research and graduate teaching. The facts, however, are quite to the contrary. Doctoral departments supply an extremely large part of undergraduate physics education.

Data from surveys (8) conducted by the American Institute of Physics (Table 4) show that of 260,000 undergraduates enrolled in 1987–88 in introductory physics courses (usually as freshmen or sophomores) in four-year colleges and institutions, 159,120 (61%) were in physics departments in which the highest degree awarded was the doctorate. The others were students in bachelor's-degree granting institutions or master's-degree granting institutions. Of the 6412 juniors majoring in physics in 1987–88, 3030 (47%) were students in doctoral institutions. Also,

of 5959 senior physics majors in 1987–88, 2991 (50%) were reported to be studying in doctoral institutions. Some 2473 (47%) of the bachelor's degrees in physics in 1986–87 were awarded by doctoral institutions. Data such as these cannot be overlooked in determining the proper targeting of Federal programs in support of undergraduate physics education.

The record is also clear concerning the important role of doctoral institutions in the improvement of the undergraduate physics laboratory. The contributions of the Berkeley Physics Course Laboratory and the University of Maryland Project were mentioned above. Those of California Institute of Technology (the invention of the air track), Columbia University (laboratory work based on the history of physics), Rensselaer Polytechnic Institute (innovative laboratory equipment for teaching modern physics), Massachusetts Institute of Technology (freshmen participation in physics research projects), the University of Washington (laboratory work designed for minorities), and Princeton University ("Physics for the Inquiring Mind") provide further examples, and many others could be cited. Doctoral institutions have provided leaders, innovative ideas, and practical examples for the strengthening of undergraduate laboratory work and have been full partners with non-doctoral institutions in physics education.

*B. Negative effects of exclusion.*

The inability of the National Science Foundation in the past to make grants to doctoral physics departments under the Instrumentation and Laboratory Improvement Program has not affected all such departments equally. Budgets for the purchase of teaching equipment differ among such departments in both source and amount. Equipment budgets are provided by the institutions, the moneys deriving from State funds (in public institutions) or from general funds or special grants (in private institutions). In some universities, the proceeds of student laboratory fees are assigned to departments.

How physics departments in doctoral institutions evaluate their equipment problem in undergraduate education is revealed by the results of a 1988 survey by AAPT of a small, but reasonably representative, sample of such departments. A few departments reported that they were satisfied with their recent progress, sometimes because of special one-time allocations of funds. Others reported that their budgets, although not generous, were sufficient to maintain existing apparatus, replace some deteriorated items, and make some gains in refurbishing and upgrading the laboratory. *Most,* on the other hand, said they believed the situation was steadily deteriorating and that the teaching laboratories were on a slippery slope. Quotations from the returns throw some light on the situation:

- "Existing state funds are not even sufficient to maintain the labs, much less improve them."
- "It's relatively easy to get money for large courses, but not for the small typical upperdivision physics courses."
- "We feel strongly about laboratory exposure for non-majors in physics courses (~4000 [students]/yr). This function is completely separate from research grants in the department."
- "Little has been done for years. There is a need for dedicated faculty with time off from regular teaching assignments and funds to spend."
- "Laboratories are essential to the proper teaching of physics. They are also the hardest element of introductory courses to do well, and they are surely the most heavily criticised by students."

Statistically, the returns in the survey show that these institutions place a high priority on recommending to funding agencies that they assist in equipment purchases and laboratory development. Over 86% of the respondents in 1988 rated such programs first in priority among the nine initiatives listed in Table 1; the rest placed them second. All but one of the respondents said that existing departmental budgets were not adequate for strengthening teaching laboratories on a reasonable time table. When asked what they estimated was the total need for funding to upgrade their teaching laboratories to an excellent standard over a five-year period (adjusting for inflation), the chairpersons answered with figures ranging from $100,000 to $1,000,000, with an average estimate of $407,000. They reported in most cases that matching funds from non-Federal sources would be available, preferred individual matching percentages ranging from 0 to 50%, with an overall average of 26%.

In view of these indications that doctoral physics departments have for some years identified equipment shortcomings as their foremost undergraduate educational problem, one cannot avoid the conclusion that their exclusion from a major Federal program directed at the problem has had serious negative effects on the quality of physics education on these campuses. It is necessary to remember that the institutions and their physics faculties are not the major losers in this situation. It is rather their students who are being deprived: about 160,000 enrollees in introductory physics courses and some 6000 undergraduate physics majors each year.

*C. The research-equipment issue.*

Doctoral physics departments receive funds from a variety of Federal agencies under research grants and contracts, a considerable portion of which are for the purchase and maintenance of equipment used in research by physics faculty, postdoctorals, and graduate students. In the

larger departments such support amounts to millions of dollars annually. An appropriate question, therefore, is why such departments need still more equipment to meet their undergraduate teaching responsibilities.

The answer is straightforward. To a limited degree, research equipment does help in undergraduate teaching: in providing the basis for an exciting, intellectually stimulating, research-based environment for undergraduates; in furnishing opportunities for research participation by physics majors; and, when it becomes outmoded for research and is "de-commissioned," in supplying components and occasionally main units that can be adapted to pedagogical purposes in advanced undergraduate laboratories.

Most Federal research grants and contracts, however, provide that research equipment purchased under them may not be used for any purposes other than those specified in the research proposal, thus excluding undergraduate teaching. Nor could state-of-the-art research equipment in physics departments – even if it were legally available – meet the need of doctoral departments for equipment for undergraduate teaching: 1) needless to say, the specialized physics for which it is designed is usually far afield from the basic physics that is of concern in the introductory courses; 2) built to enhance research productivity, such equipment usually lacks the "pedagogical transparency" that is so important in educating undergraduate physics majors; 3) even if the equipment were pedagogically suitable, teaching schedules mesh poorly with research schedules; and 4) research equipment is almost always in a form that cannot be inexpensively duplicated to provide multiple set-ups in teaching laboratories.

The conclusion in regard to instrumentation for introductory teaching is that doctoral institutions are on essentially the same footing as those that do not award doctorates. Even for advanced undergraduate laboratories the advantages are minor.

## V. What Should Be Done?

### *A. The locus of responsibility.*

It has been noted that the NSF Instrumentation and Laboratory Improvement Program (ILIP) and its predecessor, which from FY 85 through FY 88 have made a major contribution to enhancing undergraduate laboratory work in four-year and two-year non-doctoral institutions, has not hitherto been able to fund any of the proposals it has received from doctoral institutions. With the exception noted above, the NSF has assigned the responsibility for improving undergraduate laboratory work in doctoral institutions broadly to the research directorates in the related fields. These directorates, however, have lacked both funds and a sense of high priority for supporting teaching improvements and have not responded.

*AAPT recommends, therefore, that the Instrumentation and Laboratory Improvement Program within the Directorate for Science and Engineering Education be assigned the sole responsibility within NSF of administering an expanded ILIP to which bachelor's-, master's- and doctor's-degree institutions and two-year colleges would be eligible to apply on equal terms.* The SEE staff in ILIP is experienced in meeting such responsibilities and with appropriate augmentation could carry out such an expanded assignment satisfactorily.

### *B. Funding.*

It is not advisable to divert funds from the two-year and four-year colleges and master's institutions to accommodate grants to doctoral institutions. The progress being made in upgrading undergraduate laboratories in the former must be continued. *AAPT recommends that add-on funds be provided in the ILIP budget, bringing the total (all fields) to $25,000,000 in FY 1990 and $27,000,000 in FY1991.* ILIP statistics from past years would suggest that total physics awards should at least double also to $1,500,000 in FY 1990 and $1,700,000 in FY 1991. In fact, the size of the equipment problem in physics suggests that $2,000,000 and $2,500,000 respectively would be more appropriate.

We have arrived at these figures in physics by noting that the number of undergraduates (and the instrumentation requirements) included will roughly double if the program is expanded as recommended above, but also that the average amount requested is likely to increase.

### *C. Terms of the competition for awards.*

*AAPT recommends that all eligible institutions – two-year and four-year colleges and master's- and doctor's-degree awarding institutions – compete for a common pool of funds, adequate in amount, under uniform standards for judging proposals.* In a program in which success depends upon the excellence of the proposal, AAPT sees no need to recommend sub-categories for institutions of different types. Likewise, allocation of funds among the different fields of science and engineering covered by the program should not be pre-arranged, but should depend on the number of excellent proposals in each field.

### *D. Laboratory development.*

The ultimate goal of "laboratory development" is providing interesting, real-world laboratory experiences that support teaching and learning for undergraduates with different career plans and different abilities. This goal must be kept clearly in view in ILIP proposal evaluation. *Reviewers should look for clear statements of educational goals, evidence of faculty commitment to them, and information concerning institutional progress toward them.* This does not contradict our view that national progress

toward this ultimate goal of laboratory development will require several stages, the present one being "basic equipment." Innovation in the organization and course content of the undergraduate laboratory will follow. Sections F and H below contain further suggestions that are related to laboratory development.

***E. Budget items.***

*NSF should accept inclusion of budget items that make possible the invention of new pedagogical equipment—"bread-boarding," shop work, materials and components, and related costs—to ensure that the arrival of the next generation of pedagogical apparatus is not inadvertently delayed.* Much good equipment is invented and built locally in physics departments. They should be encouraged to do so and given the necessary means. We realize that what we are suggesting carries with it additional responsibilities for the proposers to provide appropriate dissemination strategies for sharing innovative changes with colleagues.

***F. Improve the present laboratory situation, then support innovative change.***

It is certainly true that the physics community does not have a secure knowledge that traditional patterns of laboratory work are the best possible. However, placing a heavy emphasis on new patterns of instruction at this stage of attacking the instrumentation problem seems unwise. As described above, the urgent problem of the moment is replacing dilapidated equipment, introducing commercially available modern-physics experiments, and taking the first steps toward change in undergraduate experimentation.

*AAPT recommends that inclusion of equipment needed for replacement or the inclusion of budget items for maintenance of standard or classical apparatus should not result in automatic downgrading of a proposal.* To be sure, evidence of an interest in pedagogical innovation should be regarded as a positive element in a proposal but only as one of several criteria for judgment. There is much good equipment and many good experiments in the classical laboratory tradition.

***G. Regular evaluation.***

*ILIP should be regularly assessed by NSF to furnish a basis on which funding levels can be adjusted and procedures changed if necessary.* Periodic surveys of the condition of instrumentation in undergraduate laboratories should be conducted by the SEE Office of Studies and Program Assessment. AAPT will be happy to lend its assistance to such an effort in the field of physics.

***H. Responsibilities of physics departments and their institutions.***

The responsibility for improving undergraduate laboratory work in physics rests with the Nation's physics departments and the institutions of which they are a part. They require Federal assistance, as this paper has tried to make clear, but effective change must come from them. *This means that the physics faculty must assess their undergraduate laboratories, as to both equipment and course content; commit themselves to projects for improvement; write strong proposals to ILIP; and carry out the projects effectively when the means have been provided.*

*The colleges and universities of which physics departments are a part need to play a strong role, not only in pledging matching funds for ILIP awards, but in providing those ancillary resources (faculty time, shop facilities, basic budgets for equipment purchases and repairs, etc.) and the encouragement needed to make laboratory-improvement projects possible.* Both departments and their institutions will not need to be reminded that the ultimate beneficiaries of laboratory improvements will be their students whose education in physics is at risk in any continuation of the deterioration of the undergraduate laboratory.

## REFERENCES

1. E.F. Taylor, *Am. J. Phys.* **56**, 975 (1988).
2. *Undergraduate Science, Mathematics, and Engineering Education,* (NSB Task Committee on Undergraduate Science and Engineering Education, National Science Board, March 1986).
3. *Scientific Equipment for Undergraduates: Is It Adequate?,* (Office of Technology Assessment, U.S. Congress, September 1986).
4. *Physics Department Chair Conference on the Education of Physicists,* edited by Jack M. Wilson, (American Association of Physics Teachers and American Physical Society Education Committee, 1984).
5. Robert Resnick, "The Impact of Undergraduate Physics Programs on the Quality and Quantity of Physics Majors: An APS Survey," *Education for Professional Work in Physics,* (American Association of Physics Teachers and American Physical Society, 1986), pp. 29–41.
6. E.F. Redish, J.M. Wilson, and W.M. MacDonald, *The M.U.P.P.E.T. Manifesto: The Implications of the Microcomputer for the Physics Major's Curriculum,* (Department of Physics and Astronomy, University of Maryland, 1988).

7. *Instrumentation for Undergraduate Science and Engineering Instructional Improvement: Summaries of FY 1985 and FY 1986 College Science Instrumentation Awards,* (NSF Directorate for Science and Engineering Education, National Science Foundation, 1987).

8. Susanne D. Ellis, *Enrollments and Degrees,* (American Institute of Physics, 1988).

## ACKNOWLEDGMENTS

The project that led to the preparation of the present paper was first proposed by Robert Resnick, Professor of Physics at Rensselaer Polytechnic Institute, during his 1988 term as AAPT President. It was carried out within the Executive Office of AAPT under the supervision of Jack M. Wilson, AAPT Executive Officer. Program descriptions and data for the NSF Instrumentation and Laboratory Improvement Program were kindly provided by the staff of the Directorate for Science and Engineering Education. We also wish to thank chairpersons of physics departments in doctoral institutions for responding to the 1988 survey.